

JPL

AUTOMATION FOR DEEP SPACE VEHICLE MONITORING

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**FLIGHT COMMAND AND DATA MANAGEMENT SYSTEMS SECTION
JET PROPULSION LABORATORY**

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AUTOMATION GOALS

- **SIGNIFICANT IMPROVEMENT IN PRODUCTIVITY AND RELIABILITY**
- **APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS TO GROUND-BASED MONITORING**
- **ADVANCEMENT OF ARTIFICIAL INTELLIGENCE TECHNOLOGY**



AUTOMATION STRATEGY

- **ACTIVE INVOLVEMENT OF THE END USER**
- **INCREMENTAL DEVELOPMENT WITH REGULAR DELIVERIES TO THE END USER**
- **EMPHASIS ON USABLE, REAL-WORLD PRODUCTS RATHER THAN PROTOTYPE DEMONSTRATIONS**



RESEARCH & DEVELOPMENT ACTIVITIES

- AUTOMATED MISSION MONITORING AND ANALYSIS
- INTELLIGENT INPUT DATA MANAGEMENT
- SYSTEM-LEVEL ANALYSIS USING COOPERATING EXPERT SYSTEMS



AUTOMATED MISSION MONITORING AND ANALYSIS

- **REAL-TIME MONITORING OF SPACECRAFT AND TELEMETRY**
- **KNOWLEDGE-BASED ANOMALY ANALYSIS**
- **COMBINATION OF CONVENTIONAL AUTOMATION AND ARTIFICIAL INTELLIGENCE**
- **MULTI-MISSION APPLICABILITY**
- **TWO-YEAR HISTORY OF CONTINUOUS ON-LINE OPERATION**

JPL

**MONITOR/
ANALYZER OF
REAL-TIME
VOYAGER
ENGINEERING
LINK**

- **FUNCTIONS**
 - **REAL-TIME MONITORING**
 - **REAL-TIME KNOWLEDGE-BASED ANALYSIS**
 - **GENERAL PRODUCTIVITY ENHANCEMENT**
- **FEATURES**
 - **DATA DISPLAY AND ARCHIVING**
 - **AUTOMATED ALARM MESSAGES**
 - **HIERARCHICAL ORGANIZATION**
 - **WINDOW ENVIRONMENT**
 - **MOUSE- AND MENU-DRIVEN OPERATION**
 - **ON-LINE USER DOCUMENTATION**

IMPLEMENTATION

- DISTRIBUTED MULTI-WORKSTATION ENVIRONMENT
 - MESSAGE PASSING FOR INTERPROCESS COMMUNICATION
 - VARIABLE NUMBER OF NODES
- MULTIPLE C PROCESSES PROVIDE STANDARD AUTOMATION
 - PROCEDURAL AND ALGORITHMIC FUNCTIONS
 - USER-INTERFACE FUNCTIONS
 - REAL-TIME SPEED AND PORTABILITY
- EMBEDDED KNOWLEDGE BASES PROVIDE EXPERT REASONING
 - ANOMALY ANALYSIS
 - CORRECTIVE ACTION RECOMMENDATIONS
 - COMPATIBILITY WITH C
- GOAL- AND DATA-DRIVEN REASONING ARE COMBINED IN KNOWLEDGE-BASED ANALYSIS MODULES
- LOWER-LEVEL C ALGORITHMS PROVIDE CALCULATIONS NEEDED BY THE KNOWLEDGE BASES



MARVEL

ACHIEVEMENTS

- **SIMULTANEOUS AUTOMATED MONITORING OF THREE VOYAGER SUBSYSTEMS**
 - **COMPUTER COMMAND SUBSYSTEM**
 - **FLIGHT DATA SUBSYSTEM**
 - **ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM**
- **KNOWLEDGE-BASED ANOMALY ANALYSIS AND CORRECTIVE RECOMMENDATIONS FOR TWO VOYAGER SUBSYSTEMS**
 - **COMPUTER COMMAND SUBSYSTEM**
 - **ATTITUDE AND ARTICULATION CONTROL SUBSYSTEM**
- **CONTINUOUS ON-LINE OPERATION FOR BOTH VOYAGER SPACECRAFT SINCE AUGUST 1989**
- **SUCCESSFUL DETECTION OF ALL ANOMALIES**
 - **IMPROVED ACCURACY**
 - **IMPROVED TIMELINESS**
- **SMOOTH TRANSITION FOR POST-ENCOUNTER WORKFORCE REDUCTIONS AND CROSS-TRAINING OF PERSONNEL**
- **TRANSITION TO TOPEX, GALILEO, AND CRAFT/CASSINI**



INTELLIGENT INPUT DATA MANAGEMENT

- **MANAGEMENT OF INPUT DATA VOLUMES THAT EXCEED PROCESSING CAPACITY**
- **COMBINATION OF DECISION THEORY AND KNOWLEDGE-BASED METHODS**
- **AUTOMATION OF AN IMPORTANT REAL-TIME TRADE-OFF BETWEEN**

AMOUNT OF INPUT PROCESSED

VS

TIMELINESS OF OUTPUT



DECISION THEORY FOR MAKING TRADE-OFFS

- UTILITY THEORY AND PROBABILITY ARE USED TO SELECT THE MAXIMUM-VALUE ACTION FROM A SET OF POSSIBLE ACTIONS.
- THE VALUE (V) OF AN ACTION (X) IS DETERMINED WITH A SET OF EVALUATION CRITERIA ($i = 1$ TO n) AND WEIGHTING FACTORS (W)

$$V = \sum_{i=1}^n W_i V_i(X_i)$$

- DECISION THEORY HAS A HISTORY OF SUCCESSFUL APPLICATION TO MAKING TRADE-OFF DECISIONS IN STATIC ENVIRONMENTS.

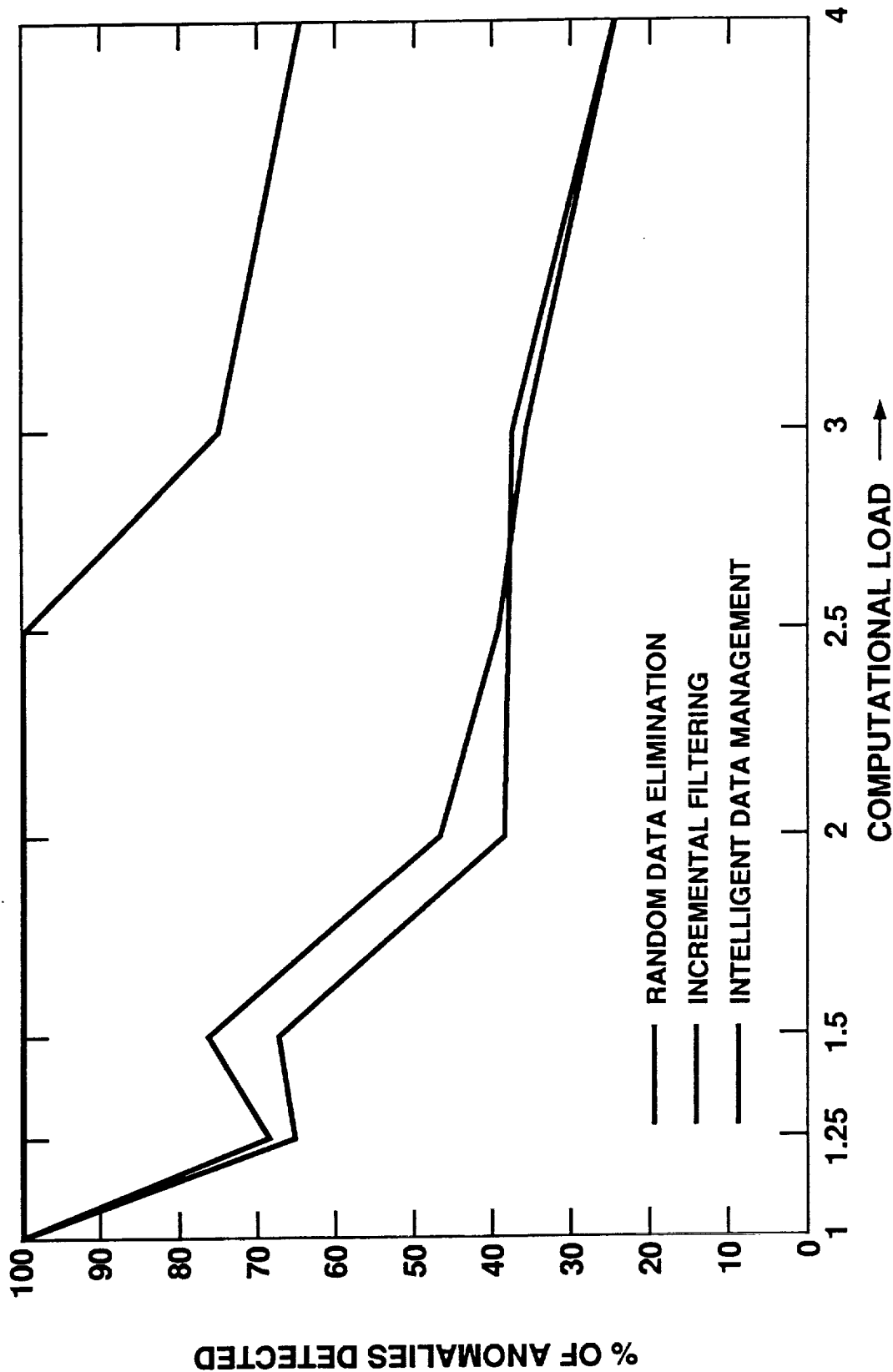


DYNAMIC TRADE-OFF EVALUATION

- EXTENDS STATIC TECHNIQUES FOR USE IN REAL-TIME ENVIRONMENTS
- USES DOMAIN KNOWLEDGE TO
 - DYNAMICALLY RE-WEIGHT THE EVALUATION CRITERIA TO REFLECT THE DYNAMICS OF THE EXTERNAL ENVIRONMENT.
 - REDEFINE COURSES OF ACTION AS DICTATED BY THE EXTERNAL ENVIRONMENT.
- HAS BEEN APPLIED TO EVALUATING THE TRADE-OFF BETWEEN THE AMOUNT OF INPUT DATA AND THE TIMELINESS OF THE OUTPUT.

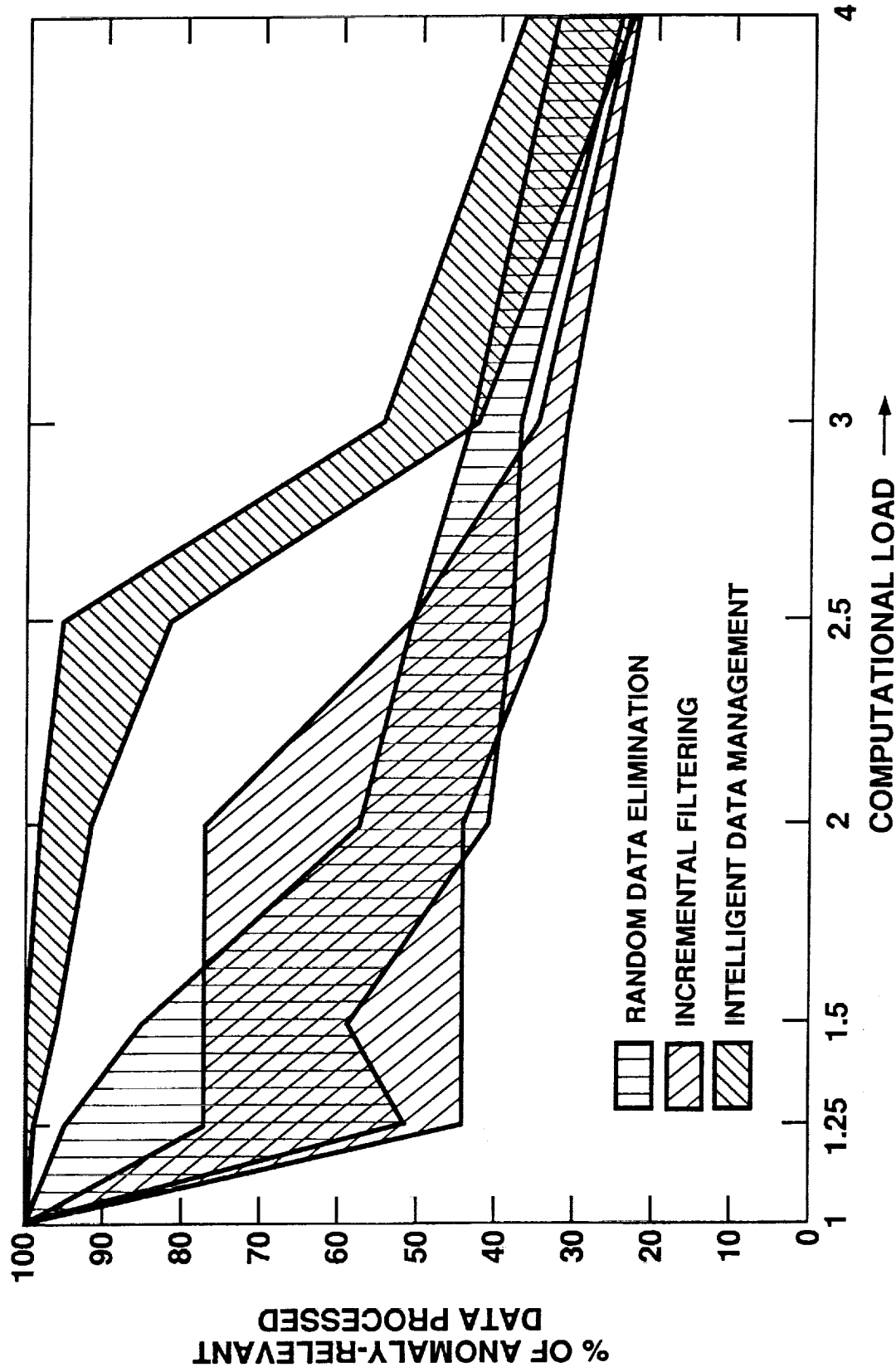
EVALUATION OF ANOMALY DETECTION RESULTS

3% ANOMALY DENSITY



EVALUATION OF DATA MANAGEMENT METHODS

3% ANOMALY DENSITY





SYSTEM-LEVEL ANALYSIS WITH COOPERATING EXPERT SYSTEMS

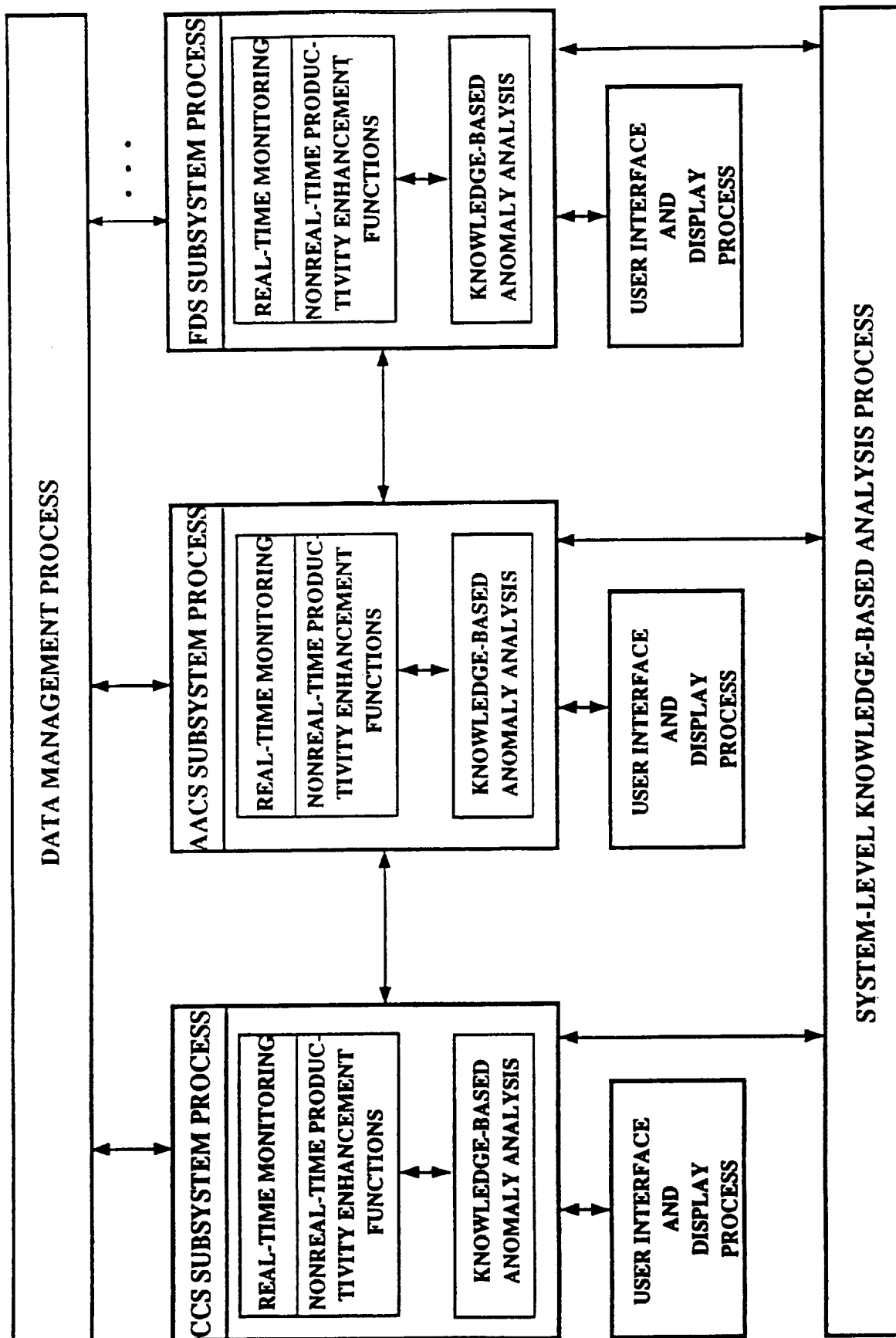
- CO-ORDINATION OF HIERARCHICAL EXPERT SYSTEMS
- COMBINATION OF DISTRIBUTED COMPUTING AND MULTIPLE USER-INTERFACES



COOPERATING EXPERT SYSTEMS

- EVENT-DRIVEN INFORMATION EXCHANGE
- DEMONS AT SUBSYSTEM LEVEL RESPOND TO SUBSYSTEM ANOMALIES
- DOMAIN KNOWLEDGE AT SUBSYSTEM LEVEL IS USED TO DETERMINE WHICH SUBSYSTEM ANOMALIES HAVE POTENTIAL SYSTEM-LEVEL IMPACT
- SUBSYSTEM DEMONS SEND MESSAGES TO SYSTEM-LEVEL KNOWLEDGE BASE
- SYSTEM-LEVEL DEMONS COORDINATE SYSTEM-LEVEL ANALYSIS

MULTIPLE EXPERT SYSTEMS DISTRIBUTED ARCHITECTURE

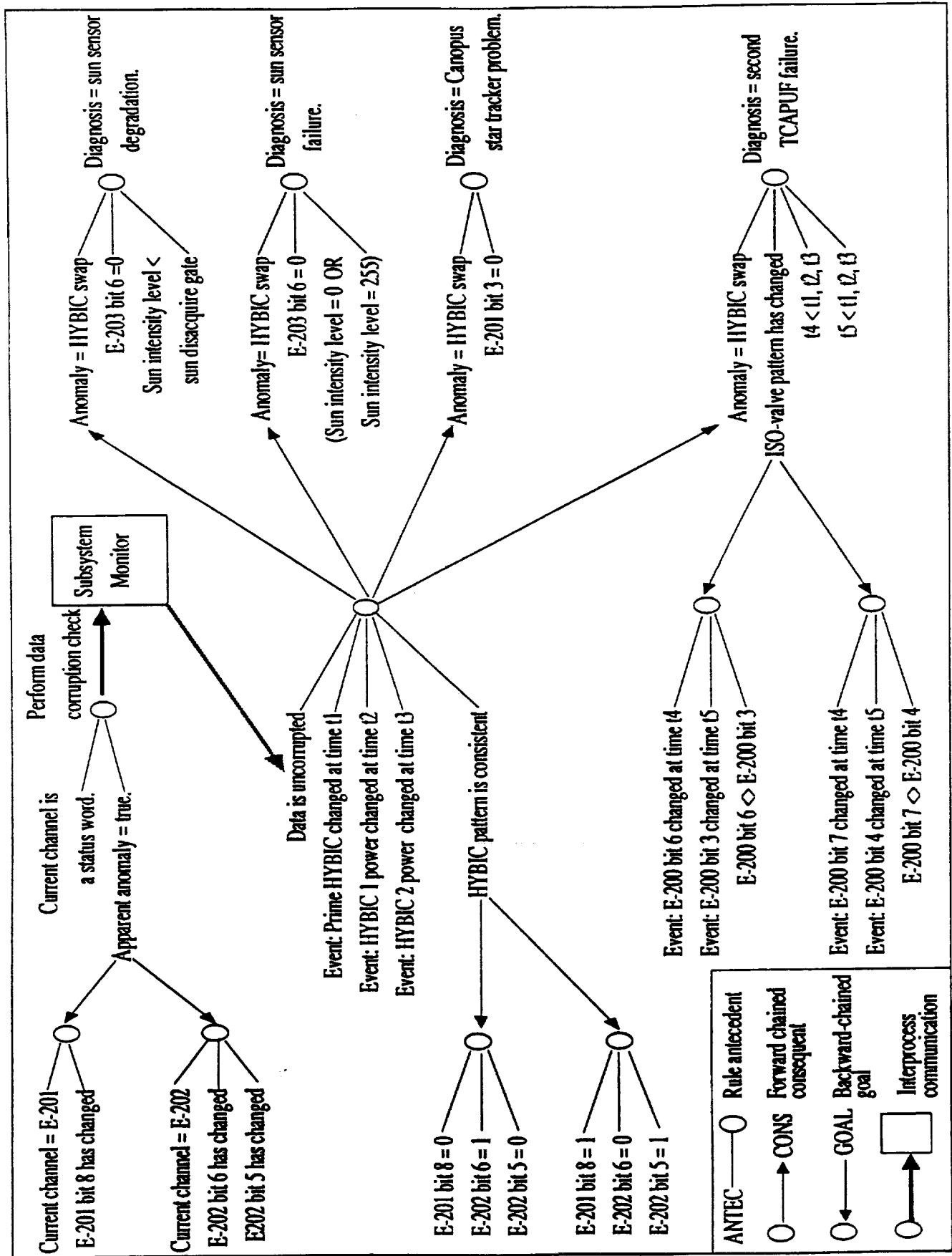




EVENT-DRIVEN RESPONSE

- DEMONS IN THE KNOWLEDGE BASE CONTROL REASONING
 - EVENT-DRIVEN RESPONSE TO ANOMALY CONDITIONS
 - INSTANTIATION OF APPROPRIATE RESPONSE PLANS
- DEMONS ARE ACTIVATED BY THE APPEARANCE OF ANOMALOUS DATA
 - TELEMETRY
 - INFERRED KNOWLEDGE FROM BACKWARD CHAINING
 - OTHER DEMONS
- BACKWARD-CHAINED PRODUCTION RULES PERFORM DIAGNOSIS
 - ANOMALY ANALYSIS
 - RECOMMENDATIONS FOR CORRECTIVE ACTION
- RULES ARE ACTIVATED BY DEMONS

EVENT-DRIVEN RESPONSE





SUMMARY

- REAL-TIME, REAL-WORLD DEMONSTRATION OF SIGNIFICANT ARTIFICIAL INTELLIGENCE CAPABILITIES
 - INTELLIGENT DATA MANAGEMENT
 - EVENT-DRIVEN COORDINATION OF KNOWLEDGE-BASED DIAGNOSTICS
 - APPROPRIATE RESPONSE TO UNCERTAIN DATA
 - MULTIPLE EXPERT SYSTEMS
- SUCCESSFUL INTEGRATION OF ARTIFICIAL INTELLIGENCE AND CONVENTIONAL AUTOMATION HAS ACHIEVED
 - FULLY-AUTOMATED, REAL-TIME MONITORING AND DIAGNOSIS
 - RECOMMENDATIONS FOR CORRECTIVE ACTION
 - PRODUCTIVITY ENHANCEMENT TOOLS
- DEMONSTRATION OF WORKFORCE REDUCTIONS AND IMPROVED PERFORMANCE